World Academy of Science, Engineering and Technology
International Journal of Physical and Mathematical Sciences
Vol:6, No:9, 2012

Numerical Simulation of Electric and Hydrodynamic Fields Distribution in a Dielectric Liquids Electrofilter Cell

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***Abstract*—**In this paper a numerical simulation of electric and hydrodynamic fields distribution in an electrofilter for dielectric liquids cell is made. The simulation is made with the purpose to determine the trajectory of particles that moves under the action of external force in an electric and hydrodynamic field created inside of an electrofilter for dielectric liquids. Particle trajectory is analyzed for a dielectric liquid-solid particles suspension.

***Keywords*—**Dielectric liquids, electrohydrodynamics, energy, high voltage, particles

I. Introduction

Electrostatic oil cleaner is a method for purging dielectric liquids using an external electric field. This method is implemented by using electrofilters. Actually are known vary types of electrofilters [1], in this paper being analyzed an electrofilter with floating potential electrodes [2]. A modeling and simulation of the electrofiltering process can be a useful method to determine if the analyzed electrofilter is productive. The simulation of the process can be made using commercial CFD software, in this paper being use the Comsol Multiphysics program which have powerful modules to solve the distribution of the electrical and hydrodynamic fields inside of the electrofilter.

To make this paper we will use the Electrostatics (emes) and Mixture Model (chmm) modules of Comsol Multiphysics program.

II. Physical Model

An electrofilter for dielectric liquids is considered, Fig. 1 [3], composed of a body in the form of a vertical cylinder which have 0.15 m in height and 0.1 m in diameter filled with a suspension of a dielectric liquid with transformer oil.

The lower part of the electrofilter is the input of the mixture in electrofilter, the top is the output of the liquid from the electrofilter. The electrofilter cylindrical body is made of metal and is connected to the ground. Inside of the electrofilter is introduced an electrode with a high potential, symmetrically interrupted to create a non-homogenous electric field.

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The electrode with high potential is located in the center of the electrofilter body, and concentric with it, having 0.003 m in diameter and 0.14 m height, being symmetrically cut along the length at the distance of 0.002 m. Between the electrodes with high potential and electrofilter case, concentric with them, 2 intermediate electrodes with floating potential are positioned, in the form of circular discs with central circular windows. All electrodes with floating potential have the diameter of central circular window of 0.01 m, outer diameter of 0.05 m and a thickness of 0.005 m.

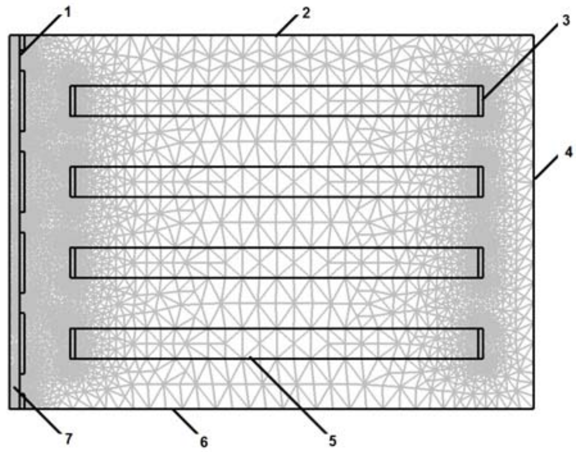

Fig. n1 Electrofilter for dielectric liquids, 2D axial symmetrical section (mesh):1- insulation, 2 – outlet, 3- insulation, 4 - electrofilter body, 5 - floating potential electrodes, 6 – inlet, 7 - high potential electrode (axial symmetry)

The electrodes with high potential and with floating potential are made of metal, high potential electrode cross paths are positioned symmetrically between the electrodes with floating potential.

The electrophysical properties of electrofilter materials and of the suspension are defined when the boundary and subdomains conditions are set.

To analyze the electric field, *Electrostatics* (emes) module is used in which next boundary and subdomain conditions are set:

Boundary condition

-electrofilter shell is connected to ground, $V = 0$; electrofilter have 0 charge $\boldsymbol{n} \cdot \boldsymbol{D} = 0$; for the electrodes with floating potential, $\int \rho_s = Q_0$; for the electrode with high potential, $V=V_0$, $V_0=5000V$.

Subdomain condition

-for the dielectric liquid subjected to purging, transformer oil with no additives, electrical conductivity, $\sigma = 0,1\cdot 10^7$ S/m; for the electrodes with floating-potential, electrical conductivity, $\sigma = 5.998\cdot 10^7$ S/m, (cooper); for the electrodes with high potential, electrical conductivity, $\sigma = 5.998\cdot 10^7$ S/m, (cooper); initial conditions for electric potential, $V_{t0}=0$;

[1] To analyze the hydrodynamic field, *Mixture Model* (chmm) is used with next boundary and subdomain conditions:

Boundary condition

-at the walls that form the case of electrofilter and at the inner electrodes of electrofilter, will be set the flow conditions, $u \cdot n = 0$, $u_d \cdot n = 0$; at the electrofilter down lid, will be set the input pressure of liquid in electrofilter, $[\eta(\nabla \boldsymbol{u} + \nabla \boldsymbol{u}^T)]\boldsymbol{n} = 0, p = p_0$, $u_d\cdot n=0$, $p=2\cdot 10^5$ Pa; at the electrofilter up lid, will be set the output pressure of liquid from electrofilter, $[\eta(\nabla \boldsymbol{u} + \nabla \boldsymbol{u}^T)]\boldsymbol{n} = 0, p = p_0$, $u_d\cdot n=0$, $p=2\cdot 10^5$ Pa;

Subdomain conditions

- continuous phase density, $\rho_c = 895 Kg/m^3$; dynamic viscosity of continuous phase, $\eta_c = 92 \cdot 10^{-3}$;
- dispersed phase, solid particles; disperse phase density, $\rho_c = 3 \cdot 10^2 Kg/m^3$; disperse phase diameter, $d_d=2\cdot 10^{-6}$ m; the flow of mixture is homogeneous, $\boldsymbol{u}_{slip} = 0, \eta = \eta_c(1 - \phi_d / \phi_{max}) \wedge (-2.5\phi_{max})$; the mixture viscosity model, Krieger model; in initially moment the volume fraction of dispersed phase is phid2(t_0)=0, $m_{dc}=0$; predefined elements, Lagrange-P_2P_1, $m_{dc}=0$;

Simplifying hypothesis

- due to the micron particle size, the forces of gravity in volume is invalid, g=0, **F**=0;

III. Mathematical Model

The electrostatics interface use the next equation for the electric potential V,

$$-\nabla \cdot (\varepsilon_0 \varepsilon_r \nabla V) = 0 \quad (1)$$

where ε_0 and ε_r is the permittivity of vacuum and the relative permittivity

The mixture model is a macroscopic model for flow of two phases. The model examines each phase concentration or volume fraction, solving the equations to determine the speed of each phase.

Mixture-Model application is based on the model of two fluids by Euler-Euler method. The mixture model consists in a continuous liquid phase and in a phase that consists in disperse particles.

The mixture model is based on the following simplifying hypothesis:

-The density of each phase is approximately constant;

-Both phases are subject to the same pressure;

The mixture momentum equation is:

$$\rho \boldsymbol{u}_t + \rho(\boldsymbol{u} \cdot \nabla)\boldsymbol{u} = -\nabla p - \nabla \cdot (\rho c_d (1 - c_d) \boldsymbol{u}_{slip} \boldsymbol{u}_{slip}) + \nabla \cdot \tau_{Gm} + \rho \boldsymbol{g} + \boldsymbol{F} \quad (2)$$

where **u**- velocity (m-s), ρ-density (kg/m^3), p-pressure (Pa), c_d-masic fraction of dispersed phase (Kg/Kg), $\boldsymbol{u}_{slip}$-relative velocity between the two phases (m/s), τ_{Gm}-sum between turbulent and viscous stress (Kg/m·s^2)), **g**-gravity vector (m/s^2), **F**- force in volume (N/m^3). Velocity **u** is the speed of mixture (m/s), defined as:

$$\boldsymbol{u} = \frac{\phi_c \rho_c \boldsymbol{u}_c + \phi_d \rho_d \boldsymbol{u}_d}{\rho} \quad (3)$$

where ϕ_c and ϕ_d is the volume fraction of continuous and dispersed phase (m^3/m^3), $\boldsymbol{u}_c$-continous phase velocity(m/s), $\boldsymbol{u}_d$-disperse phase velocity (m/s), ρ_c-continous phase velocity (kg/m^3), ρ_d-disperse phase velocity (Kg/m^3), and ρ-mixture density.

In this application is assumed that the density of each phase is constant, the equation of continuity for the mixture can be written as:

$$(\rho_c - \rho_d)[\nabla \cdot (\phi_d (1 - c_d) \boldsymbol{u}_{slip} - D_{md} \nabla \phi_d) + m_{dc} / \rho_d] + \rho_c (\nabla \cdot \boldsymbol{u}) = 0 \quad (4)$$

where m_{dc} is the mass transfer rate between disperse phase and continuous phase (kg/(m3·s)).

The report between the mass transfer rate of disperse phase and continuous phase and between dispersed phase densities is given by the equation:

$$\partial \phi_d / \partial t + \nabla \cdot [\phi_d \boldsymbol{u} + \phi_d (1 - \phi_d \rho_d / \boldsymbol{u}_{slip}] = -m_{dc} / \rho_d \quad (5)$$

To coupling these two physics is need to specify the electric force, which is:

$$\boldsymbol{F} = \nabla \cdot \boldsymbol{T} \quad (6)$$

where $\boldsymbol{T}$ is the Maxwell stress tensor,

$$\boldsymbol{T} = \boldsymbol{E}\boldsymbol{D}^{\boldsymbol{T}} - \frac{1}{2}(\boldsymbol{E} \cdot \boldsymbol{D})\boldsymbol{I} \quad (7)$$

where $\boldsymbol{E}$ is the electric field and $\boldsymbol{D}$ is the electric displacement field:

$$\boldsymbol{E} = -\nabla \cdot V \quad (8)$$

$$\mathbf{D} = \varepsilon_0 \varepsilon_r \mathbf{E} \quad (9)$$

The force given by the divergence of the Maxwell stress tensor is [4],

$$F = -\frac{1}{2}(\boldsymbol{E} \cdot \boldsymbol{E})\varepsilon_0 \nabla \varepsilon_r \tag{10}$$

IV. Modeling and Analysis of Numerical Results

Comsol is able to simulate separately for each application so after setting the boundary and subdomain condition, described above, first step is to solve the equations for Electrostatics module.

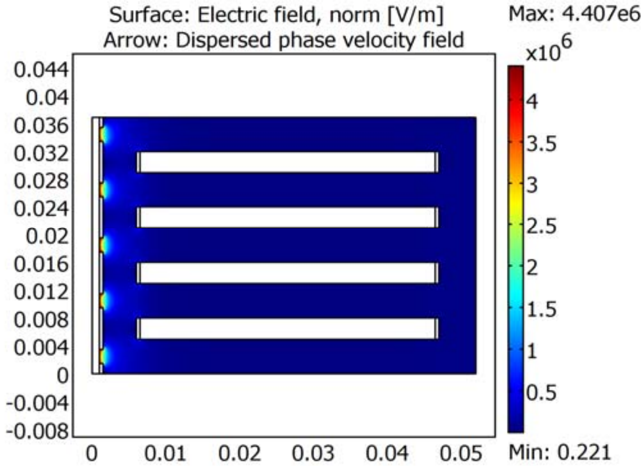

Fig. 2 Electric field distribution in an electrofilter for dielectric liquids

Applying at the central electrode a potential V = 5000 V, the electric field distribution is reproduced in Fig. 2. The maximum strength of the electric field obtained from simulation is $E=4.407 \cdot 10^6$ V/m. The field lines distribution is reproduced in Fig. 3. The field lines have a direction from the central electrode to the electrofilter case, passing through the floating potential electrodes, creating good conditions for particles to coagulate in that area and to sediment on the floating potential electrodes.

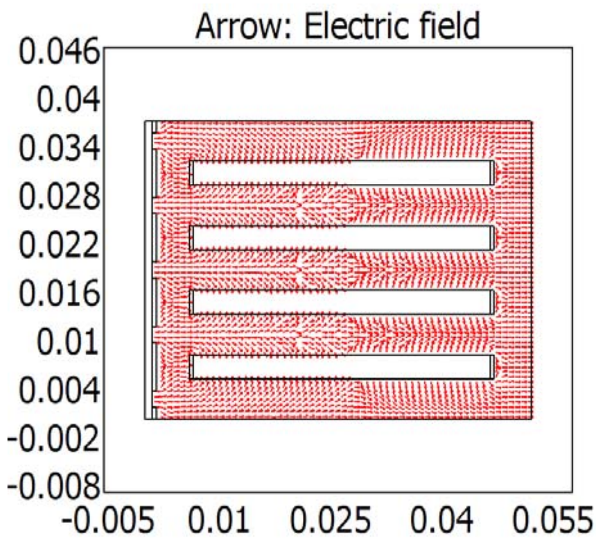

Fig. 3 Distribution of electric field lines within electroseparator

In Fig. 4 was plotted the volume fraction of dispersed phase between the floating potential electrodes on 5 horizontal axes. It can be observed that the masic flux of the particles close to the central electrode rise, these because the high electric field value in that area.

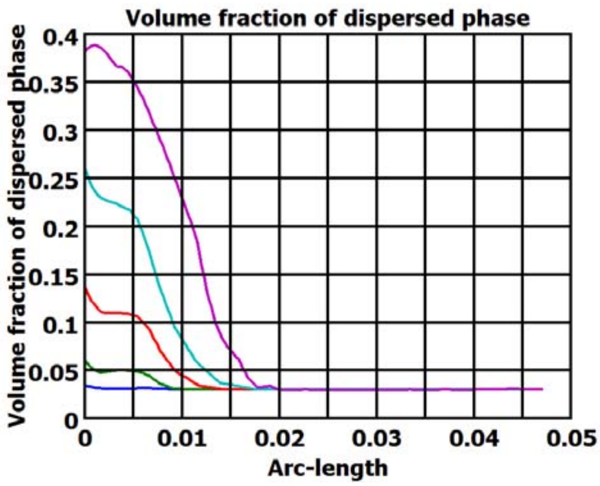

Fig. 4 Volume fraction of dispersed phase after t=100, [s]

Dispersed phase velocity is plotted in Fig.. 5. Under the influence of electric field, dispersed phase velocity is higher close to the central electrode, on the same points as in Fig. 4. If we compare these figure with fig. 2, it can be observed that the dispersed phase velocity is higher in the where the electric field is at maximum value. Analyzing figure 2-4 we can conclude that particles are attracted by the electrostatic forces and as next proposed work the distance between the central electrode and the floating potential electrode can be modified to analyze and to find an optimum distance to decrease the speed of the particles at the central electrode and to favorites the transport of the particles to the floating potential electrodes.

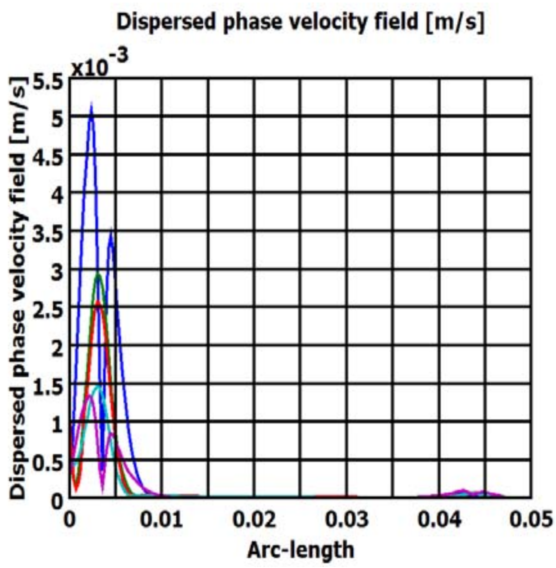

Fig. 5 Dispersed phase velocity, t=100, [s].

V. Conclusion

The CFD software used for numerical simulation of electrical and hydrodynamic fields distribution in an electrofilter for dielectric liquids cell are useful to visualize and a better understanding of the electrostatic oil cleaner process. The electric field distribution in the analyzed electrofilter is inhomogeneous and favorites the coalescence and transport of particles to the floating potential electrodes of the electrofilter. At the edges of the floating potential electrodes a turbulence of the fluid occur with a negative influence on the process. A future work is proposed based on the present paper, with the scope to optimize the dimension and the distance between the electrodes of the electrofilter for a better distribution of the electric field lines of force inside of the electrofilter.

References

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